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Validation of GOSSYM: Part II. Mississippi Conditions*

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SUMMARY

Validation of the cotton simulation model GOSSYM was carried out with data collected from two locations during three different years in Mississippi to: (1) identify areas of the model which need to be improved to provide a universal cotton simulation model, (2) develop versions of GOSSYM with site-dependent or cultivar-dependent parameters as necessary for immediate use.

Equations to calculate canopy temperatures were developed from data collected at Mississippi State Plant Science Farm, and carbohydrate partitioning logic was changed in the model giving high priority for bolls under carbohydrate stress conditions. The GOSSYM simulations were very close to real data collected during two different seasons at Mississippi State.

For validating GOSSYM with data from Stoneville, Mississippi, we incorporated lygus damage into the simulated crop to give a realistic comparison with the real crop. We believe the data support a lygus population in the field plots of sufficient numbers to cause damage equal to the fruit loss we put into the simulation. Changes during this validation and the reasons for them are discussed.

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INTRODUCTION

Models of mechanical systems originating from engineering sciences are, in general, based on detailed knowledge of the theory of the underlying processes, for which exact mathematical descriptions are available. Hence, such models hardly require experimental validation. In the biological sciences we are dealing with dynamic systems that are not man-made, and in many areas our understanding of the basic principles is fragmentary. Models of biological systems are often no more than expressions of opinion about their structure and behavior, without any supporting evidence of their validity.

Validation of a biological model should therefore be an important part of the simulation. Computer models should be tested at all stages with the results obtained from experimenting with the real system. The validation may also lead to the design of relevant experiments and increase our understanding of the system.

The objectives of the present study were: (a) to collect a comprehensive validation data set for the cotton simulation model GOSSYM, (b) to validate the model and identify the areas of the model which need to be improved to provide a universal cotton simulation model as a long-range goal, (c) to develop versions of GOSSYM with site-dependent or cultivar-dependent parameters and (d) to determine the feasibility of developing a general process-level cotton simulation model.

MODEL BACKGROUND

Several simulation models have been developed for cotton. In the late 1960's Stapleton in Arizona began an effort to simulate cotton growth to provide a basis for making decisions in cultural management and the selection of machinery, power and labour combinations. This effort resulted in the first digital-computer simulation of cotton growth (Stapleton, 1970). Later Stapleton & Meyer (1971) reported on a second-generation model which resulted in a more comprehensive analysis of some of the components of the first model.

A similar, and somewhat more detailed, effort was begun in 1969 at Mississippi State University by Duncan *et al.* (1971) and Duncan (1972), which resulted in SIMCOT. This model used the concept of a 'standard plant' in calculating growth and yield. SIMCOT was modified by the

Mississippi State group by incorporating new knowledge gained from experiments by Hesketh *et al.* (1972a, 1972b) and Baker *et al.* (1972). Nutritional theory of available substrate versus maximum usable substrate was applied to the model to calculate stress effects on shortages of carbohydrates and nitrogen. Jones *et al.* (1974) added the nitrogen budget routine. These efforts resulted in a second-generation model named SIMCOT II (McKinion *et al.*, 1975). It provided a reliable simulation of crop photosynthesis, respiration and morphogenesis under well-watered conditions, and accounted for stress physiology relationships. However, the soil–plant relationships were handled rather crudely.

Baker *et al.* (1983) developed the third-generation model GOSSYM, which incorporated better data on the effects of temperature and water stress on growth and morphogenesis as well as a detailed root rhizosphere model, RHIZOS (Lambert & Baker, 1984). GOSSYM is a dynamic simulator which grows the cotton plant from emergence to open bolls, accounting for the major physiological and morphogenetic processes and also the main interrelationships in the soil–plant system.

MODEL FEATURES AND RATIONALE

The detailed concepts and structure of GOSSYM have been presented on several occasions (Reddy, 1981; Baker *et al.*, 1983; Lambert & Baker, 1984). Since the cotton crop has a tremendous ecological range, the cotton simulation model was designed to simulate crop growth and development over a wide range of climates, soils, plant populations, cultivars and management practices (Baker *et al.*, 1983). GOSSYM is a dynamic materials-balance model. Photosynthesis, respiration and growth change rapidly with temperature, light intensity and plant water status. The materials-balance concept in GOSSYM is introduced in Fig. 1. Here standard systems dynamics notation is used; rectangles represent material pools of definite size, indefinite-size pools are represented by the irregular enclosures, the valve-shaped characters represent regulation of flow rates between pools, solid lines represent material flows, and dashed lines represent information flow. The plant model contains pools of nitrogen and labile carbohydrates which arrive via the transpiration stream and the photosynthetic processes, respectively. These materials flow to the leaves, stems, fruits and roots. The

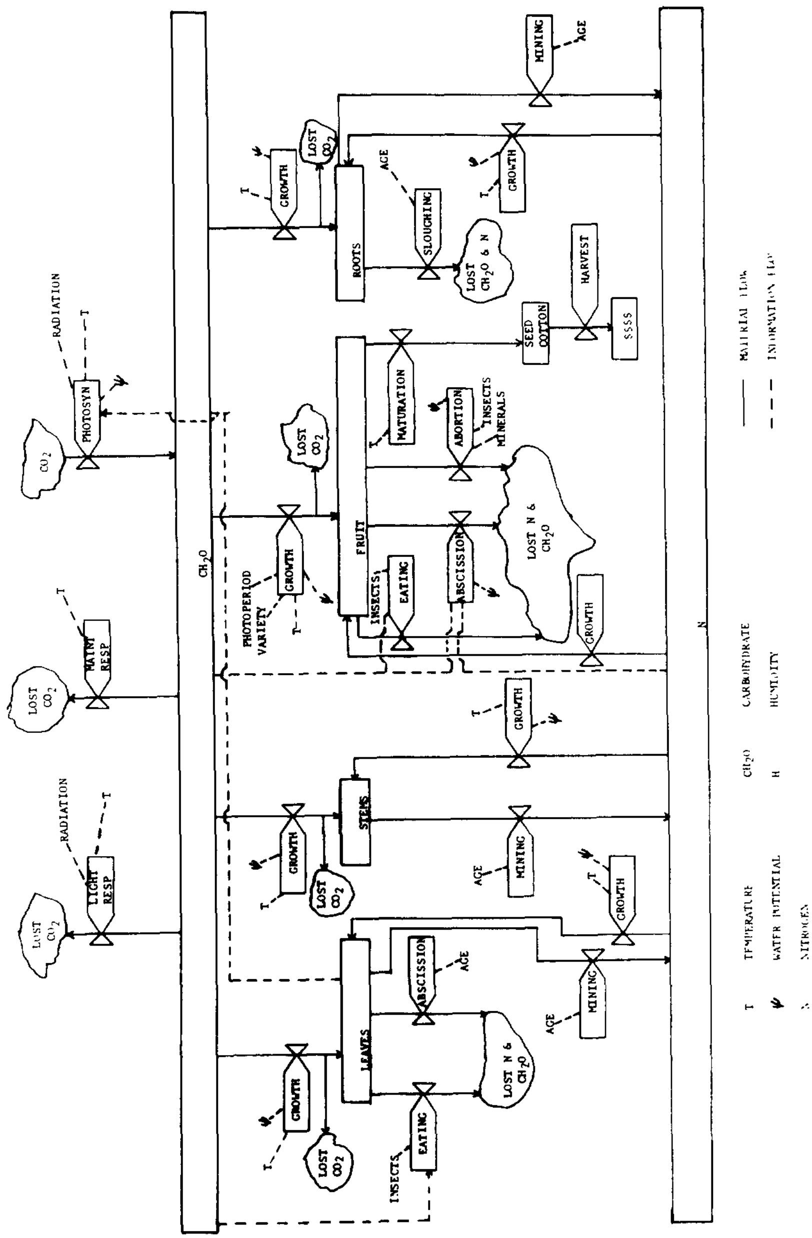

Fig. 1. A systems dynamics conceptualization of the nitrogen and carbohydrate materials balance in cotton.

model depicts the redistribution of nitrogen within the plant. The initiation of organs on the plant occurs as a series of somewhat discrete events, with rates depending on temperature and the physiological status of the plant. Various losses occur as a result of insect damage and the normal plant senescence and abscission in response to physiological stress.

In general, the plants' responses to environmental factors are as follows: photosynthesis depends on light intensity and light interception, and is reduced by water stress. Respiration depends on temperature and plant biomass. Growth is a function of temperature, tissue turgor and metabolite supply. Thus, plant water status is a determinant of both supply and demand for metabolites. Water stress reduces photosynthesis, transpiration and nitrogen uptake. It also reduces growth and the demand for nutrients. The supply:demand ratios for carbohydrate and nitrogen are used as indices of stress-induced time delays for morphogenetic events. We assume that the metabolic supply:demand status of the plant determines hormone balances which alter the morphogenetic rates. This status also determines or shifts the balance in hormone systems which result in the abscission of fruit. Thus, while morphogenetic rate is driven by temperature, it is affected indirectly by those factors determining the supply and demand for carbohydrates and nitrogen. Thus, the combination of a severe moisture stress and a heavy boll load may stop new node formation, while a mild moisture stress which reduces vegetative growth more than supply may have no effect or cause a relative increase in morphogenetic rate.

Environmental inputs necessary to run GOSSYM are solar radiation, maximum and minimum temperatures, rainfall and/or irrigation water, all on a daily basis. Additional inputs necessary to run GOSSYM are emergence date, plant population, row spacing, latitude of the site, nitrogen fertility level, wind speed, and information concerning physical, hydraulic and water-holding properties of the soil.

Output from GOSSYM includes water and nitrogen status of the soil, plant height, nitrogen concentration of different organs of the plant, number of fruit abscissed, number of squares, green bolls, open bolls, fruiting sites, and vegetative and fruiting branches. Also, the model provides plant maps indicating the position of the fruit remaining on the plant. This information can be printed out on a daily basis or as desired by the operator. At the end of the season, the model calculates lint yield in kg per hectare.

MATERIALS AND METHODS

To validate the cotton simulation model GOSSYM, plant map data were collected at two locations in Mississippi. The plant map data for Mississippi State location included the number of squares, bolls, fruiting sites, main stem nodes, plant height and leaf area index, and for the Stoneville location it included fruiting sites, main stem nodes and plant height at weekly intervals, in addition to estimates of insect damage and final yield. Also obtained were emergence date, plant population, row spacing, latitude of the site, nitrogen fertility level, wind speed, and information concerning physical, hydraulic and water-holding properties of the soil.

We also collected weather data for the crop-growing season including total solar radiation, maximum and minimum temperatures, pan evaporation and rainfall, on a daily basis.

Reddy and Baker's data

These data were collected in clay loam soil at Mississippi State Plant Science Farm in the summer of 1980. The weather was hot and dry with maximum temperatures as high as 43 °C and the crop was grown without irrigation. The field was planted on 28 May 1980 with the variety DPL-61, and plants were thinned to a population of 98 000/ha when they were 15 cm tall. The crop was sprayed at weekly intervals for insects. At the time of planting, the field was fertilized with 128 kg N/ha, 36 kg P_2O_5/ha and 36 kg K_2O/ha. The field received a total of 278 mm of water as rain during the growing season. Each plot had 4 rows at 1 metre apart and there were 4 replications.

Destructive observations were made and data collected from 28 sample plants on the numbers of squares, bolls, fruiting sites, main stem nodes and plant height. Plant dry weights and leaf area indices were also obtained from 10 of the above-mentioned plants harvested at weekly intervals (Tables 1 and 2). Yield was recorded from all the plots at the end of the season and seed cotton samples were ginned to calculate the percentage of lint. In these plots, we also recorded the canopy temperatures at 8 points in the canopy on 4 different plants. The temperatures were recorded by installing thermocouples in the canopy. Twenty-gauge AWG shielded thermocouples with 4-mm junctions were installed in the canopy. The thermocouples were isolated from direct solar

TABLE 1
Cotton (Deltapine 61) Plant Growth Data (per Plant) on Numbers of Squares, Bolls, Mainstream Nodes, Fruiting Sites and Plant Height, Mississippi State, Mississippi, 1980*

Day after germination	*Number of*				*Plant height (cm)*
	Squares	*Bolls*	*Mainstem nodes*	*Fruiting sites*	
24			8·54 ± 0·10		19·91 ± 0·52
31	3·75 ± 0·51		13·50 ± 0·33	3·92 ± 0·60	26·46 ± 0·83
39	13·75 ± 1·60		16·07 ± 0·29	14·94 ± 1·46	31·95 ± 1·39
46	27·86 ± 2·09	0·07 ± 0·05	17·64 ± 0·54	29·46 ± 2·56	44·58 ± 1·70
53	30·89 ± 2·84	1·50 ± 0·22	19·00 ± 0·52	33·43 ± 3·02	51·14 ± 2·18
60	33·82 ± 2·74	5·57 ± 0·67	21·57 ± 0·38	42·21 ± 3·46	66·66 ± 2·00
67	31·39 ± 2·91	10·25 ± 1·20	23·04 ± 0·50	47·14 ± 3·90	74·03 ± 2·41
74	23·79 ± 2·14	13·68 ± 1·19	23·43 ± 0·35	45·61 ± 3·25	81·40 ± 2·20
85	9·93 ± 0·97	13·14 ± 1·00	23·14 ± 0·39	42·46 ± 2·66	81·65 ± 2·36
93	8·43 ± 0·76	12·25 ± 1·06	24·68 ± 0·31	55·11 ± 3·61	84·96 ± 2·03
117	5·09 ± 1·29	8·00 ± 0·58	23·55 ± 0·66	47·73 ± 2·45	84·16 ± 3·15

* Data presented as mean ± standard error of the mean.

TABLE 2
Cotton (Deltapine 61) Plant Growth Data on Dry Weights of Leaves, Stems, Bolls and Leaf Area Index. Mississippi State, Mississippi, 1980*

Day after germination	*Dry weights (g/plant)*			*Leaf area index (LAI)*
	Leaves	*Stems*	*Bolls*	
24	0·73 ± 0·14	0·24 ± 0·04		0·18 ± 0·03
31	2·26 ± 0·42	1·12 ± 0·21		0·47 ± 0·07
38	4·31 ± 0·92	2·65 ± 0·62		0·84 ± 0·16
45	6·15 ± 1·16	4·50 ± 0·89		1·13 ± 0·19
52	9·15 ± 2·05	7·64 ± 2·08	1·03 ± 0·65	1·48 ± 0·31
59	9·60 ± 1·00	9·29 ± 1·19	1·53 ± 0·52	1·88 ± 0·16
67	15·41 ± 2·31	16·57 ± 2·71	9·71 ± 1·73	3·06 ± 0·42
73	18·49 ± 4·23	19·99 ± 4·34	23·78 ± 6·63	3·70 ± 0·85
80	16·24 ± 2·56	20·34 ± 2·83	28·51 ± 4·86	3·37 ± 0·55
87	13·97 ± 1·71	18·37 ± 1·90	36·55 ± 4·38	2·64 ± 0·29
94	14·18 ± 0·89	21·77 ± 2·54	50·63 ± 5·32	2·46 ± 0·15
108	9·17 ± 1·89	18·43 ± 2·90	50·56 ± 7·08	1·45 ± 0·28
115	7·09 ± 0·88	13·70 ± 2·00	38·79 ± 9·38	1·22 ± 0·11
123	6·21 ± 1·33	13·16 ± 3·29	34·27 ± 5·13	0·98 ± 0·14

* Data presented as mean ± standard error of the mean.

radiation by installation in a black plastic tube covered with aluminium foil beneath the leaf. Thermocouples were positioned to prevent direct contact with the leaves, stems or solar-protection tubes. The temperatures were recorded at 1/10 second intervals by a MODCOMP II computer located nearby. With this detailed canopy temperature data, we derived equations to calculate average temperature of the canopy for day and night from maximum and minimum air-temperatures.

Bruce and Römkens' data

These data were collected on Deltapine haploid M8948 American upland cotton in clay loam soils at Mississippi State, Mississippi. The plants were grown under a rain-out shelter at a density of 50 630 plants/ha in 91-cm rows. Prior to planting, 67 kg/ha of P_2O_5, 335 kg/ha of K_2O and 84 kg/ha of N were applied. At 4-week intervals after planting, 3 additional applications of 84 kg/ha of N were applied making a total of 336 kg/ha of N for the season. Throughout the season, intensive insect control practices were employed and minimum damage was experienced. The weather was hot and humid and both treatments were well watered from planting to the time of the first flower; they were then irrigated whenever the average water potentials at 15, 30, 45 cm depth fell below $-0{\cdot}6$ and $-1{\cdot}2$ bars respectively for treatments *ABB* and *ACC*. Ten plants per plot were selected when plant height was about 15 cm. The plant map data and plant heights were recorded at regular frequent intervals. The yields were determined from harvesting 2·8 square metre areas.

Jenkins' data

These data were collected from plants grown in sandy loam soil at Stoneville, Mississippi under humid and hot weather conditions during 1976. The fields were fertilized with 112 kg N/ha at the time of planting. The crop was planted to an established population of 103 740 plants/ha in the fourth week of May and grown without any irrigation. Numbers of fruiting sites, main stem nodes, and plant height were collected at weekly intervals and the final yield was recorded at the end of the season. The plants were sprayed for insects but some damage was recorded from *Lygus lineolaris* (tarnished plant bug) and these insects were counted during the season (Table 3). We selected three data sets, from strain DPL 7146N and cultivars 'Deltapine 16' (DPL-16) and 'Stoneville 731N'

TABLE 3
Number of Lygus Bugs Recorded per Hectare During the 1976 Growing Season, Stoneville, Mississippi

Cultivar	*22 June*	*29 June*	*6 July*	*13 July*	*20 July*	*27 July*
DPL 7146N	323	323	2 580	1 291	644	968
DPL 16	1 936	323	4 519	2 259	644	1 936
ST 731 N	968	0	4 840	644	323	2 580

(ST731N) for validation purposes. Detailed data of weather and soil properties were obtained. The fields received 500 mm of rainfall water during the growing season. Plots were 14 rows by 14 metres length, replicated 4 times.

VALIDATION PROCEDURE

The cotton simulation model GOSSYM was originally calibrated for the Mississippi rain-out shelter data of Bruce & Römkens (1965), treatment *AAA*. Next, the model was validated with the data of Bruce and Römkens' treatments *AAA* and *ADD* and Fye's data from Arizona (Fye *et al.*, 1984). With this version of the model, we tried to simulate the Mississippi State Plant Science Farm cotton data for 1980 and tried to find parameter changes necessary to simulate both Bruce & Römkens' (1965) data (treatments *ABB*, *ACC*) and our 1980 data. These two crops were grown at the same location, but with different cultivars, plant populations, fertilizer and other cultural practices.

With the same version of the model, we tried to simulate cotton data collected at Stoneville, Mississippi. We made some changes in the code pertaining to plant bug damage to simulate the Stoneville data. The final version of the model simulated all the above data sets with the changes discussed below.

RESULTS AND DISCUSSION

Reddy and Baker's data, Mississippi State, Mississippi

Changes in the model

For Mississippi conditions GOSSYM calculates average temperatures for day (TDAY) and night (TNYT) as a function of maximum (TMAX) and minimum temperature (TMIN). Based on air and canopy temperatures collected in the same field, we developed two regression equations to transform average air temperatures to average canopy temperatures for day (CANTDAY) and night (CANTNYT) as follows:

$$\text{CANTDAY} = 2{\cdot}396\,33 + (1{\cdot}056\,97{*}\text{TDAY})\ R^2\ (0{\cdot}99)$$
$$\text{CANTNYT} = 2{\cdot}781\,67 + (0{\cdot}915\,15{*}\text{TNYT})\ R^2\ (0{\cdot}99)$$

In GOSSYM plant growth and morphogenesis calculations are based on canopy temperatures.

Physiological age of each node (AGENODE) is calculated as a function of chronological age of each node (AGE) and sum of carbohydrate delays (SCDLAY) multiplied by a calibration parameter (CBL) as follows:

$$\text{AGENODE} = \text{AGE} - \text{SCDLAY}{*}\text{CBL}$$

We increased the parameter CBL value from 0·19 to 0·7 to slow the ageing of the nodes in response to dry conditions experienced during this season.

When available carbohydrates are insufficient to meet the demand of growing organs, we assign a priority to different organs for the allocation of available carbohydrates. Sabbe & Cathey (1969) reported that from the time of flowering, fruits are the regions of rapid growth and are more active metabolic sinks than the roots which were the most active sinks prior to flowering. It has also been reported for tomato that at the time of fruit development, the expansion of leaves is considerably reduced and root death at early fruiting appears to be more severe (Hurd & Mountifield, 1978). This demonstrates a change in partitioning priorities within the plant when the fruits are formed.

Ho (1978) reported that the rate of fruit growth may be determined by the process of unloading sucrose at the fruit. The hydrolysis of imported sucrose and subsequent synthesis of starch appears to limit the unloading process and the activity of acid invertase appears to be key factor in controlling the rate of carbon import (Walker *et al.*, 1978).

The reasoning for the suggestion that hydrolysis of sucrose limits the rate of carbon import is that, first, 90% of the imported assimilate is sucrose but the sucrose concentration in growing fruits is only 0·1 to 0·3% of fresh weight, and secondly, the rate of carbon import is inversely proportional to the fruit sucrose concentration, implying that the rate of carbon import is closely related to the rate of hydrolysis of imported sucrose and subsequent starch or cellulose synthesis (Ho, 1978).

It has also been reported that the total available carbohydrate levels or sucrose levels along cotton plant axes are lowest where the developing bolls are located, whereas available carbohydrates are highest in leaves, followed by leaf petioles, stems and roots.

This evidence suggests that there is a shift in carbohydrate partitioning after the fruits are formed and that this shift is toward fruits. We can also see lower amounts of available sugars near the fruiting bodies, which gives rise to the speculation that the amount of acid invertase in fruit is high to allow more sucrose hydrolysis, which controls the translocation of sugars to fruit.

Changing the GOSSYM code in the GROWTH subroutine from earlier versions of GOSSYM, under carbohydrate stress conditions, we assigned up to 70 % of available carbohydrates to square and boll growth. The leaves were assigned second priority and they received up to 30 % of the remaining available carbohydrates. As a third priority, 75 % of the remaining carbohydrates were assigned to the stem growth. The roots got the remainder. These parameter values were derived from data sets from Israel (Marani, personal communication; Reddy, 1981) and data from Mississippi State which were collected during this study.

This is a major change in the carbohydrate allocation because earlier versions of the model assumed no priority between different plant parts. In our earlier validation studies we did not have data on time course of dry weights of bolls, stems and leaves. But with the data from Israel (Reddy, 1981) and the data we collected at Mississippi State, we have the time course of boll weight, leaf weight and stem weight. In order to simulate these time courses of dry weights, we found it necessary to incorporate the above priorities between plant parts for carbohydrate allocation. The modification of carbohydrate partitioning remained in the model as an improvement for simulating data sets from other locations including Fye's data from Arizona (Fye *et al.*, 1984).

While validating GOSSYM with this data set, another general improvement was made to the model. We incorporated better logic for calculation of maintenance respiration. These modifications improved GOSSYM simulation for all the locations and remained in the model as general improvements.

Validation results

The simulated soil water potential at the root zone fluctuated from −0·3 to −2·12 bars throughout the season for this data set (Fig. 2).

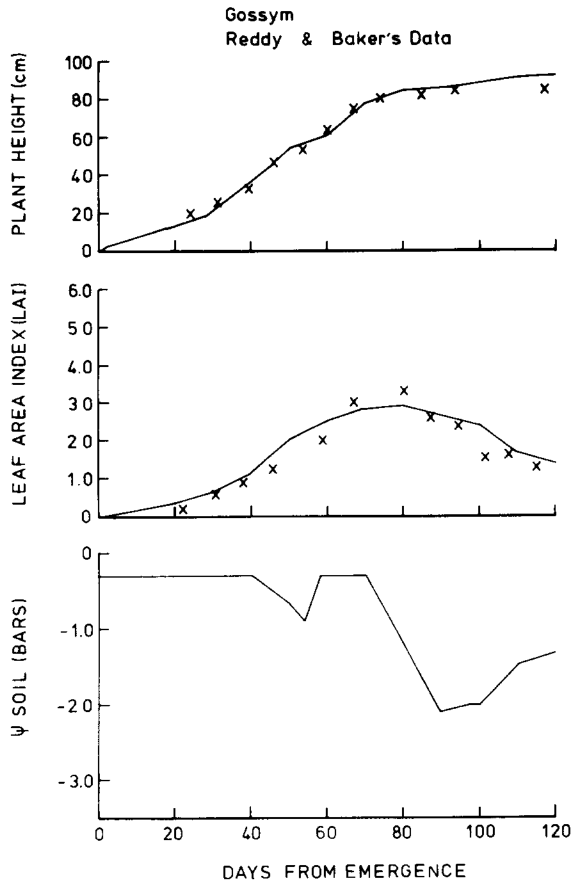

Fig. 2. A comparison of the seasonal progression of the plant height, leaf area index and the simulated soil water potential of GOSSYM with observations of Reddy and Baker's data.

The GOSSYM simulation of plant height and leaf area index (LAI) is very accurate showing a good agreement with the real plant height and LAI throughout the season (Fig. 2). The simulations of the numbers of squares and bolls are in good agreement with the observed data. The GOSSYM simulation on number of fruiting sites is very similar to real fruiting sites (Fig. 3) except at the end of the season where the real fruiting sites decreased because of abortion of nodes on the fruiting branches (Mauney, personal communication) and because scars formed after the abscission of pinhead squares cannot be identified easily and may not

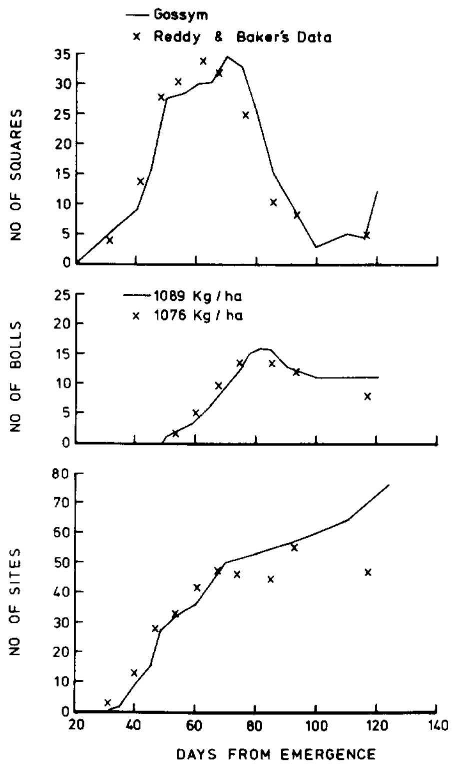

Fig. 3. A comparison of the seasonal development of the number of squares, bolls and fruiting sites of GOSSYM with observations of Reddy and Baker's data.

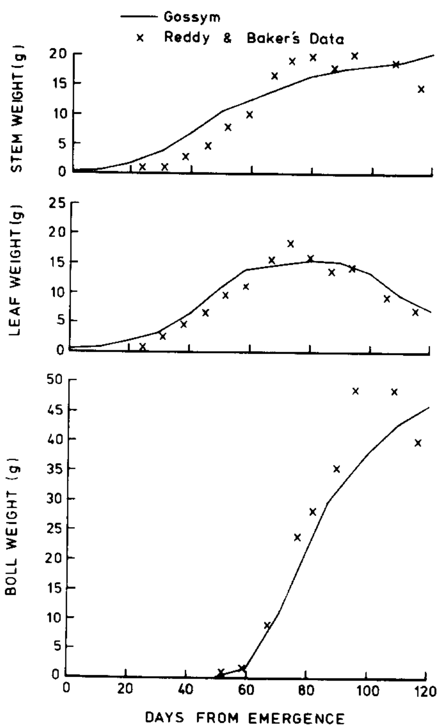

Fig. 4. A comparison of the seasonal progression of the dry weight of stems, leaves and bolls of GOSSYM with observations of Reddy and Baker's data.

have been counted. The simulation of the stem dry weight (Fig. 4) is close to the real dry weight until day 110, after that the simulation shows a gradual increase in the stem dry weight whereas the real data show a very small decrease in the stem dry weight. This decrease in the stem dry weight might be due to abortion of fruiting branches during the hot, dry season and this can also be seen in the decrease of fruiting sites at the end of the season (Fig. 3). The simulation of leaf dry weight and boll dry weight is close to the real leaf and boll dry weight, respectively, throughout the season (Fig. 4). The variation between real and simulated data is always close to the standard error of the real data (Tables 1 and 2) for all the plant parameters. Simulated yield is 1089 kg/ha, which is very similar to the real yield of 1076 kg/ha.

Bruce and Römkens' data, Mississippi State, Mississippi

For simulating Bruce and Römkens' data, treatments *ABB* and *ACC*, we changed the calibration parameter CBL value from 0·7 to 0·19 which speeded up the formation of fruiting sites and the rest of the modifications remained in the model as improvements.

The model predictions for treatments *ABB* are very close throughout the season for plant height, number of mainstem nodes, squares, bolls and fruiting sites (Figs. 5 and 6). The real yield was 1397 kg/ha which is very close to the predicted yield of 1455 kg/ha. Model predictions for treatment *ACC* were also close for all plant parameters (Figs. 7 and 8).

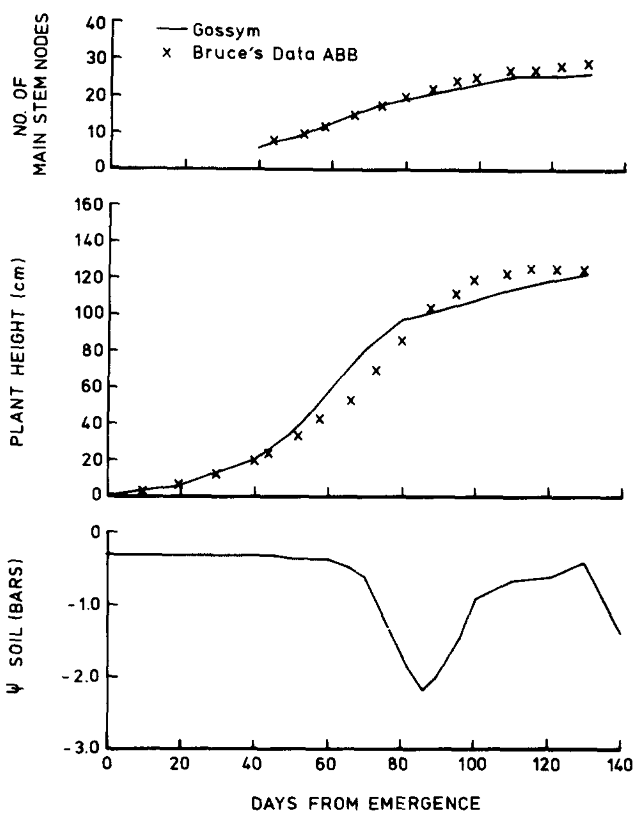

Fig. 5. A comparison of the seasonal development of the number of mainstem nodes, plant height and the simulated soil water potential of GOSSYM with observations of Bruce's data treatment *ABB*.

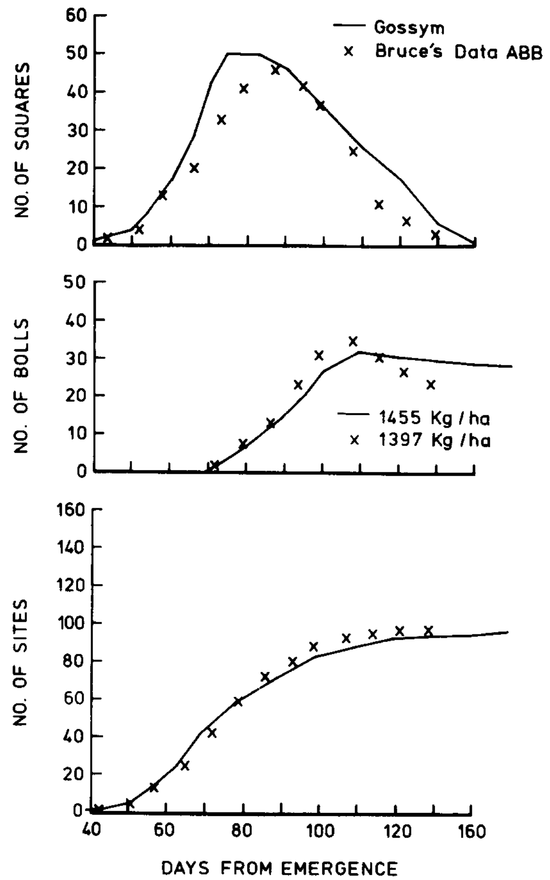

Fig. 6. A comparison of the seasonal development of the number of squares, bolls and fruiting sites of GOSSYM with observations of Bruce's data treatment *ABB*.

The model predicted a yield of 1410 kg/ha compared to the real yield of 1355 kg/ha.

Jenkins' data, Stoneville, Mississippi

Changes in the model

During the validation with these data we made very few changes in the model. Insect counts from the field indicated a substantial number of lygus bugs (Table 3). Several computer runs were made incorporating insect damage of different intensities by removing part of the fruiting

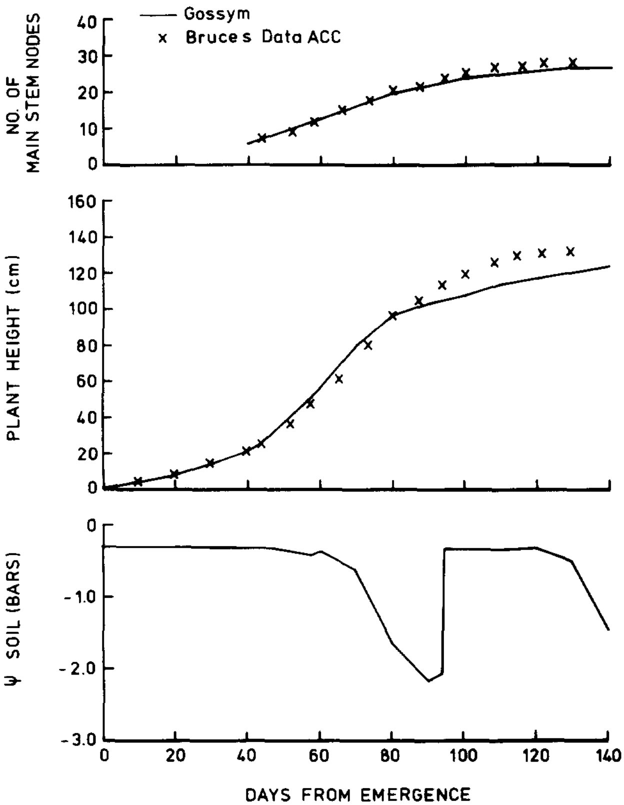

Fig. 7. A comparison of the seasonal development of the number of mainstem nodes, plant height and the simulated soil water potential of GOSSYM with observations of Bruce's data treatment *ACC*.

branches and dropping flower buds. In an analysis of plant bug feeding patterns on cotton, Mauney & Henneberry (1979) reported damage of 3·69 squares per *Lygus hesperus* nymph per day at 30 °C. This is slightly more than double the feeding rate reported by Gutierrez *et al.* (1979). Gutierrez *et al.* (1979) reported that adult females feed at approximately double the rate of adult males. Their data show feeding rates for nymphs similar to the rates for the adult females. Since there appears to be enough controversy we selected a feeding rate of 3 squares per day per insect without regard to sex or developmental stage and aborted the squares based on lygus population given in Table 3. Neither Mauney *et al.* (1979) nor Gutierrez (1979) evaluated damage, i.e. yield loss resulting from the

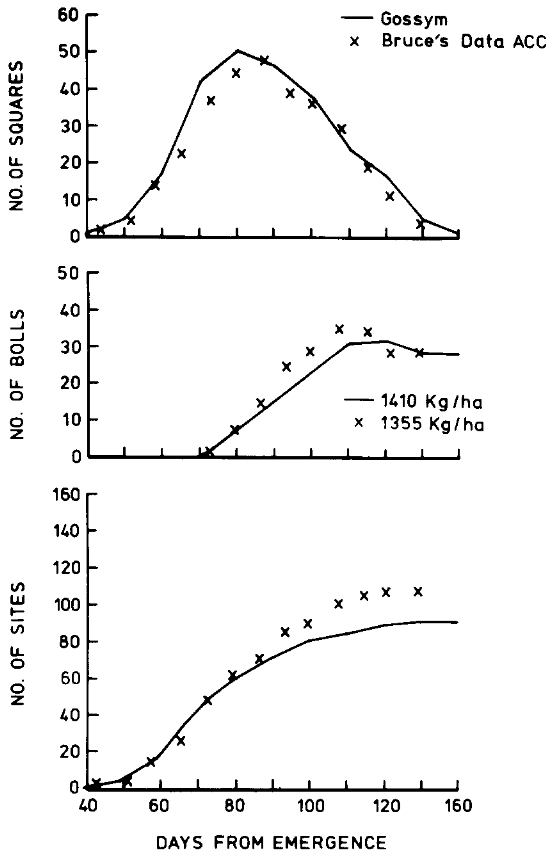

Fig. 8. A comparison of the seasonal development of the number of squares, bolls and fruiting sites of GOSSYM with observations of Bruce's data *ACC*.

termination of fruiting branch development with the resultant failure of some early square initiation. We felt that under Mississippi conditions this could be a significant source of yield loss because of decline in temperatures toward the end of the season. So we aborted fruiting branches 2, 3 and 4 at their first nodes uniformly for all the crops. This way of simulating insect damage is very crude and the model needs to be equipped with a separate subroutine to simulate insect population and the resulting damage.

We made several computer runs and found it necessary to change two parameter values to simulate these data sets. The delay in forming new nodes on vegetative branches (VDELAY) due to different stresses is calculated as a function of physiological stress (FSTRESS), carbohydrate delays in vegetative branches (CDLAYV) and nitrogen-induced delays (NDLAY) as follows:

$$\text{CDLAYV} = 1{\cdot}0 + \text{FSTRES* } (\text{XTR}_2 + \text{XTR}_3\text{*FSTRES})$$
$$\text{VDELAY} = \text{CDLAYV} + \text{NDLAY}$$

We increased the calibration parameter values XTR_2 from $-0{\cdot}55$ to $-0{\cdot}30$ and XTR_3 from $-5{\cdot}50$ to $-3{\cdot}00$ to increase the effect of carbohydrate delays in delaying morphogenesis. We believe that these changes in parameter values were needed because the carbohydrate delay (CDLAYV) is a function of water stress which has been identified as an area that needs improvements (Fye *et al.*, 1984). With these modifications, GOSSYM accurately simulated the cotton crop of Stoneville, MS. Thus the Stoneville data show some areas where the model needs improvements, i.e. in insect damage and morphogenesis under water stress conditions.

Validation results

The simulated soil water potential at the root zone fluctuated from $-0{\cdot}3$ to $-2{\cdot}60$ bars throughout the season for all the varieties from Stoneville (Figs. 9, 10, 11). The simulated plant height is very close to the real data for DPL7146N (Fig. 9) until day 65; after that there is some scatter in the real data showing a decrease in plant height on day 79 over the previous observation which was on day 73. This is probably due to sampling error, but the model shows a gradual increase in the plant height which is quite reasonable. The model simulation in the case of number of mainstem nodes and fruiting sites is very close to the real data. Simulated yield for this strain is 413 kg/ha, also very close to real yield of 423 kg/ha. The simulation for DPL16 shows a good agreement between simulated and real data on the number of mainstem nodes, fruiting sites and plant height (Fig. 10). The simulated yield (391 kg/ha) was very close to the real yield (397 kg/ha) for this variety.

For ST731N from Stoneville, the simulated plant height is close to real plant height except for days 65 and 74 (Fig. 11). However, these simulated points are close to the standard error of the real data. The real and simulated number of mainstem nodes and fruiting sites are very close throughout the season (Fig. 11). The simulated yield for this variety was 413 kg/ha and the real yield was 348 kg/ha.

In order to simulate Bruce and Römkens' cotton crop with the version

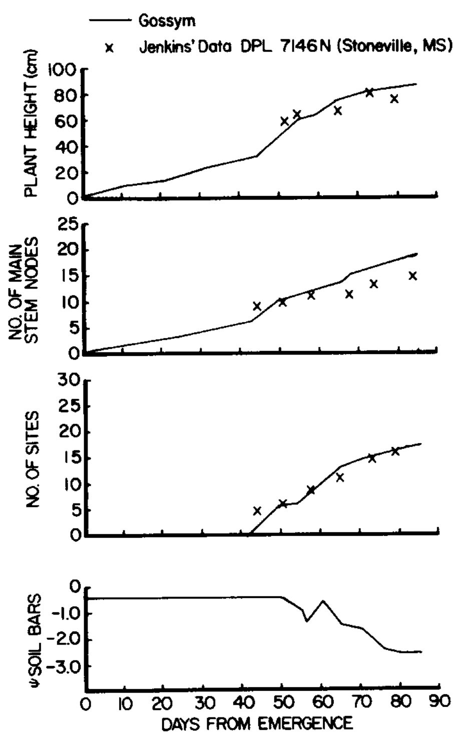

Fig. 9. A comparison of the seasonal progression of plant height, number of mainstem nodes, fruiting sites and the simulated soil water potential of GOSSYM with observations of Jenkins' data for variety DPL 7146N.

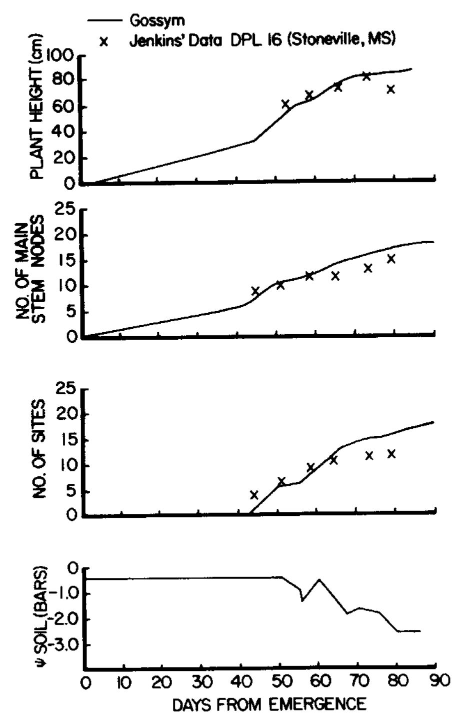

Fig. 10. A comparison of the seasonal progression of plant height, number of mainstem nodes, fruiting sites and the simulated soil water potential of GOSSYM with observations of Jenkins' data for variety DPL 16.

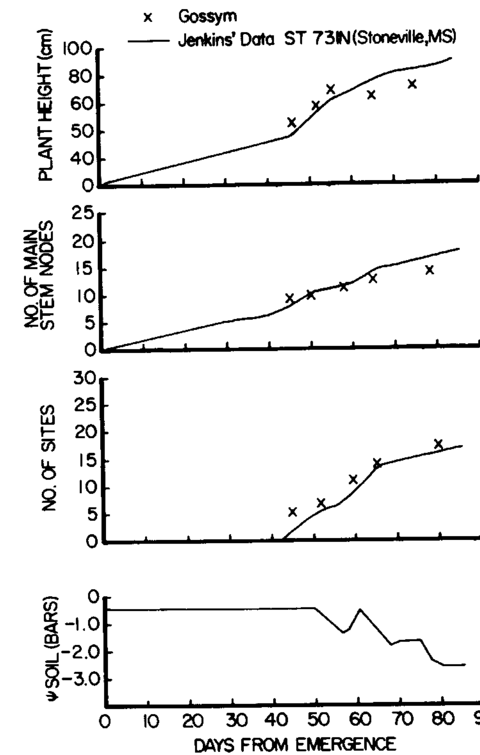

Fig. 11. A comparison of the seasonal progression of plant height, number of mainstem nodes, fruiting sites and the simulated soil water potential of GOSSYM with observations of Jenkins' data for variety ST 731N.

of GOSSYM which simulated the Stoneville cotton crop, we removed the equations which simulated insect damage for Stoneville data. The delays induced by carbohydrates were changed to their original form. With these few parameter modifications, GOSSYM simulated Bruce and Römkens' cotton crop. Here again, as in the case of previous locations (Reddy, 1981; Fye *et al.*, 1984), we believe that these parameter changes were needed because of the weakness of the model in the area of water stress and its present lack of subroutines to deal with insect damage to the crop.

CONCLUSIONS

A comprehensive set of validation data was collected from a cotton crop grown at Mississippi State Plant Science Farm in 1980, and the cotton simulation model GOSSYM was validated with data collected at two locations in Mississippi.

Changes made to GOSSYM during validation with Reddy and Baker's data, Jenkins' data and Bruce and Römkens' data was a change in partitioning under carbohydrate stress conditions to assign 70% of the available carbohydrates to square and boll growth. With these changes the model predictions were close to the real data on all the plant parameters we compared. The changes for simulating the cotton crop from Stoneville, Mississippi pertained to the effect of insect damage on cotton and the effects of water stress on morphogenesis. The model simulation results compared very well with the real data.

Bruce and Römkens' data were collected from plants under rain-out sheltered plots, where data were collected on the same plants throughout the season and plant growth disturbance was severe due to continuous mapping of plants. The few parameter changes we made for validating GOSSYM with data from Stoneville, Reddy and Baker's data and Bruce and Römkens' data, is probably due to the above error in the Bruce and Römkens' data. Also, the input data regarding the exact amount of water applied is approximated because we do not know the run-off percentage of water when irrigation or rainfall occurs. Some of the variations between simulated and real data could be attributed to this.

During this validation work and also the earlier validation efforts (Reddy, 1981; Fye *et al.*, 1981; Fye *et al.*, 1984), the few changes we made to the code pertained to the model's response to atmospheric demand for water which is obviously different from location to location and relies mostly on climatic changes. We therefore speculate that the area in the cotton simulation model GOSSYM which needs to be improved is its response to water stress. Considering the complexity of the system and the fact that the number of site-specific changes needed was relatively very small, this validation process demonstrated the feasibility of a general process-level cotton simulation model.

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